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SPATIAL COGNITION AND REASONING

Perry W. Thorndyke

April 1980

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This paper summarizes several cognitive studies of spatial knowledge processing. The studies investigated the types of representation of spatial knowledge, the techniques individuals use to acquire knowledge from maps, and the differences between the knowledge acquired from maps and navigational experience. Three major conclusions emerge from these studies: (1) People encode several types of spatial knowledge in memory, including images of physical objects, memory of actions and procedures, symbolic abstractions of the environment (e. g., names, distances), and spatial maps; (2) Different types of spatial knowledge are optimal for different tasks (e. g., orienting oneself, estimating distances, reconstructing spatial relations among distant objects); (3) Individuals vary in their strategies and abilities for acquiring spatial knowledge.

PREFACE

This Note documents a paper presented at a conference on "Cognition, Social Behavior, and the Environment," held at Vanderbilt University in May 1979. The reported research was supported by the Office of the Director of Personnel and Training Research Programs, Psychological Sciences Division, Office of Naval Research, under Contract No. N00014-78-C-0042 with The Rand Corporation.

SUMMARY

Cognitive approaches to human spatial learning and reasoning differ from the traditional environmental approach. Environmental psychologists typically relate demographic and social variables to one's perception of the environment. In contrast, cognitive psychologists focus on the representation of spatial knowledge in memory and the processes used to acquire, encode, and reason with that knowledge. This paper summarizes several cognitive studies of spatial knowledge processing. The studies investigated the types of representation of spatial knowledge, the techniques individuals use to acquire knowledge from maps, and the differences between the knowledge acquired from maps and navigational experience. Three major conclusions emerge from these studies: (1) People encode several types of spatial knowledge in memory, including images of physical objects, memory of actions and procedures, symbolic abstractions of the environment (e.g., names, distances), and spatial maps. (2) Different types of spatial knowledge are optimal for different tasks (e.g., orienting oneself, estimating distances, reconstructing spatial relations among distant objects). (3) Individuals vary in their strategies and abilities for acquiring spatial knowledge.

SPATIAL COGNITION AND REASONING

During the second day of this conference, I was stopped while walking across the Vanderbilt campus by a couple who asked if I could direct them to the Holiday Inn. Although I was generally unfamiliar with the campus and its environs, I had walked between the Holiday Inn and the conference hall three times during the previous two days. Consequently, I was able to confidently point in the direction of the hotel and explain to them the best route to take in order to walk there.

This incident gave me particular satisfaction because I was able to analyze and understand my mundane (though by no means simple) behavior in that situation in terms of my research on spatial cognition, which, not coincidentally, is the topic of this paper. I use the term cognition here not in its typical sense (as synonymous with "thinking"), but in its primary literal sense, which is the process of acquiring new knowledge.[1] Thus, as the title of this paper indicates, I am concerned with how people acquire knowledge of their environment and use that knowledge to perform tasks such as, in the example above, orienting oneself in the environment and giving directions.

Situations in which we acquire new spatial knowledge or use what we know to reason are ubiquitous in our lives. They range all the way from learning to get around in a new locale by acquiring knowledge

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[1] I am grateful to Frederick Hayes-Roth for pointing out this distinction.

about the names and locations of objects in the environment to reading a map to answer particular questions about the world (e.g., What's the name of that street? Where's the Pasadena Civic Center?) People also use the knowledge they acquire to perform such tasks as estimating distances between points or deciding how to get from one location to another by the shortest route.

Spatial knowledge comes from a variety of sources. A frequent source of knowledge is a map, which provides a concise symbolism for a vast amount of geographic information, and so is particularly useful for finding information or answering questions rapidly. But most typically, people acquire knowledge from navigational experience. They travel through the world, observe objects, locations, and routes, encode that information in memory, and integrate it all into a coherent representation of the world. In this paper I will postulate some of the types of spatial knowledge that people have in memory, how they acquire that knowledge, and how particular knowledge types constrain performance on common spatial reasoning tasks.

The question of how people perceive and respond to their spatial environment has concerned researchers from a wide range of disciplines, including geography, psychology, architecture, urban planning, and sociology. With the exception of a few isolated early studies of spatial orientation (e.g., Trowbridge, 1913; Witkin, 1946; Tolman, 1948), most of the psychological research on spatial cognition and reasoning has been conducted within the past twenty years. The bulk of this research has been in the area of environmental psychology (Lynch, 1960; Downs & Stea, 1973, 1977; Proshansky, Ittelson, & Rivlin, 1970; Moore & Golledge, 1976; Golledge & Rushton, 1976).

However, as evidenced by the contributions of Chase and Clayton to this volume and by other recent articles in the literature (e.g., Stevens & Coupe, 1978; Allen, Siegel, & Rosinski, 1978; Kozlowski & Bryant, 1977; Thorndyke & Stasz, 1980), cognitive and experimental psychologists have begun to study this area of human behavior too.

The recent "cognitive" approaches to human spatial reasoning (including the present paper) differ somewhat from the traditional "environmental" approach. In both approaches, researchers are concerned with what types of spatial knowledge people acquire and, to some extent, how that knowledge is represented in memory. Such knowledge includes the identities of various geographic features (e.g., landmarks, paths or routes, boundaries, and regions), the locations of these features in the environment, the distances among them, and the knowledge necessary to orient oneself in the environment. Typically, environmental psychologists focus on how people derive such spatial knowledge from their day-to-day experiences. Such studies frequently employ correlational methods to relate personal variables such as socio-economic status, mobility, attitudes, and preferences to individuals' environmental knowledge. Cognitive psychologists, in contrast, are considering maps, in addition to environmental experience, as sources of spatial knowledge. Further, instead of considering social variables as determinants of individual differences in spatial knowledge, cognitive psychologists are analyzing differences in spatial knowledge in terms of the processes individuals use to acquire, manipulate, encode, and retrieve information. Chase's contribution to this volume illustrates this approach. Such process analyses have also led cognitive researchers to consider the procedures

by which people use their spatial knowledge to perform complex tasks such as memorizing maps, estimating distances, and selecting optimal routes between points.

The remainder of this paper provides an overview to the approach my colleagues Barbara Hayes-Roth and Cathleen Stasz and I have been taking to the study of human spatial cognition. The paper is organized around three main points that will be illustrated and defended with a variety of formal and informal data. These points are:

(1) People encode several types of spatial knowledge in memory.

(2) Different types of spatial knowledge are optimal for different tasks.

(3) Individuals vary in their strategies and abilities for acquiring spatial knowledge.

The following sections treat each of these propositions in more detail.

TYPES OF SPATIAL KNOWLEDGE

Our knowledge of the surrounding world comes from a variety of sources, including maps, movies and photographs, verbal descriptions, and direct perception during navigation. It seems reasonable, then, to suppose that a person's spatial knowledge is a collection of memories that may include images of geographic features, sequences of actions that define specific routes, images (perhaps fuzzy) of area maps, and individual facts about particular objects or relationships (e.g., the distance from San Francisco to Los Angeles is approximately

400 miles). Siegel and White (1975) have postulated three fundamental types of spatial knowledge: memory for landmarks (prominent geographic features), route representations (action sequences that connect separate locations), and configural representations (map-like, global organizations of object and route relationships). A variety of other researchers, using different terminologies, have made similar distinctions and have argued that a person's knowledge typically progresses from landmark to route to configural representations (Piaget, Inhelder, & Szeminska, 1960; Shemyakin, 1962; Appleyard, 1969, 1970; Siegel, Kirasic, & Kail, 1978).

I view these distinctions as defining categories of knowledge types, which I will call landmark knowledge, procedural knowledge (knowledge of procedures for navigating between points), and survey knowledge (map-like configurations of points). Within these categories, I think it is possible to further refine the distinctions to capture differences in how detailed the knowledge is, how it is associated with related knowledge, and the form in which it is represented. Table 1 summarizes these knowledge types.

The different knowledge types may be thought of as stages in the representation of spatial knowledge. Like Clayton (in this volume), I do not think that the acquisition of knowledge necessarily follows a particular linear progression through these stages. Rather, people typically seem to have knowledge of each type about different portions of their environment. Exactly which stage best characterizes a person's knowledge depends on such factors as the extent of their navigational experience in the environment, the regularity of the geographic features in the environment, the person's motivation, whether

Table 1

TYPES OF SPATIAL KNOWLEDGE

Knowledge Category		Form of the Memory Representation
Landmark	------------>	Perceptual Icons
Procedure	------------>	Unordered Productions Ordered Productions
Survey	------------>	Symbolic Abstractions Schematized Maps Detailed Maps

or not the person has studied a map of the environment, and so on. Each of these knowledge types is described in the following paragraphs.

1. Perceptual Icons. The first type of knowledge is the memory of familiar, previously experienced locations. Such knowledge may be thought of as perceptual icons. People most typically acquire these visual memories when first encountering a new environment, such as when visiting a new city or a new area of a familiar city. As they travel through the region, they notice various objects and encode perceptual images that capture the visual scene. Repeated experience leads to the accumulation of a data base of these recognizable images of the area and their association with certain people, goals, times, and so on. Thus, people who have spent some time in a city can look through a set of photographs and identify which objects they have seen

and the names of certain buildings and locations. One might acquire these memories independently of knowledge of the relative locations of the objects in the region or of the routes connecting them.

2. Unordered productions. Most navigation behavior is goal-directed; that is, people usually travel with a destination in mind. In novel environments, people begin to acquire route knowledge by associating with their perceptual icons behaviors they perform in order to reach a certain destination. That is, they progress from a purely visual memory to a behavioral memory that associates images and actions. Such associations are like production rules, or situation-action pairs of the form "if my destination is X and I am at recognizable location Y, then perform action Z." Clayton (in this volume) refers to this type of knowledge as memory for actions in context. So, for example, if I'm traveling in Los Angeles, my destination is The Rand Corporation, and my current view when I look around includes Synanon on my left, then I know I should turn right. Along the same route, another view I might have is an intersection with a traffic signal and the Pacific Shore Hotel on the left. In this situation, I know I should turn left. People frequently acquire sets of such productions as a basis for navigating in an unfamiliar region using only memory of previous route traversals. For any particular route the individual productions are independent in that they do not represent the order or occurrence along the route, nor is there any explicit association among them. Therefore, in Table 1 knowledge of this type is referred to as unordered productions.

It is not unusual for a person to have extensive route knowledge of an environment comprising only these unintegrated route components. An acquaintance, MC, who is a native of Los Angeles, illustrates this point nicely. When asked to give directions for a moderately complex but frequently traveled route, she often replies, "I can't tell you how to get there, but I can take you there." This distinction between the ability to navigate and the ability to give directions potentially stems from two properties of the memory representation of unordered productions. First, the productions MC uses for navigation are independent and are organized in memory in no particular sequential order. So while MC can retrieve the appropriate action associated with each of the choice points, she cannot retrieve the order in which she will arrive at the points. Thus, once she arrives at a certain choice point, she knows the appropriate action to perform but she cannot regenerate the sequence of choice points. A second reason for MC's inability to give directions may be an inability to recall or explain in sufficient detail the visual features of the locations where actions must be performed. Thus, while MC can recognize these locations when she arrives at them, the image of these locations may not be sufficiently strong for her to recall them.

3. <u>Ordered Productions</u>. A related type of procedural knowledge is listed in Table 1 as <u>ordered productions</u>. This knowledge is similar to unordered productions except that order information is represented by associations between productions. So I may know, for example, that when I arrive at Synanon on my way to Rand I should turn right, and that I should next use, say, production P46. P46, in turn, may state that when I arrive at the Pacific Shore Hotel, I should turn

left and then use production P81. Thus, sequential route knowledge is represented as an associative path through a set of individual productions.

4. Symbolic Abstractions. As people become more familiar with the environment, they begin to replace their perceptual icons with symbolic abstractions, or verbal descriptions, of the region. Such symbolic information includes semantic knowledge about location names and approximate locations and distances. This semantic knowledge may supplant the perceptual information that was used previously for navigation. For example, one may learn that Rand is at the corner of Ocean Avenue and Colorado Boulevard so that it is no longer necessary to be able to recognize the building. One needs only to know the name of the corner at which to turn. As such symbolic abstractions replace perceptual icons in people's route descriptions, less attention is given to the visual details of the environment. An interesting but as yet untested hypothesis following from this formulation is that as people become more experienced in an environment, they may actually become less sensitive to perceptual details due to an increasing reliance on symbolic abstractions.

In addition to learning these symbolic labels, people may also learn other abstractions that cannot be perceived directly. Such knowledge includes global spatial knowledge of the environment, such as distances between points and their relative compass bearings or orientations. One might learn these additional facts from a map, from another person, or by computing them from direct knowledge about routes connecting the points. This survey knowledge about relative spatial locations complements the procedural knowledge for navigating

between locations. Thus, one might know not only how to get to Rand from Synanon, but that Synanon is one-half mile due south of Rand.

As the number of facts about spatial location, direction, and distance about a region grows, one builds what may be thought of as a network of spatial relations encoding knowledge about various locations. Stevens and Coupe (1978) have postulated that such knowledge is organized hierarchically in memory and that inferential processes operate on knowledge in the network to produce judgments about spatial relations. For example, one might have the following concepts and relations stored in memory: San Diego IS-PART-OF California, Reno IS-PART-OF Nevada, and California IS-WEST-OF Nevada. Using only this knowledge one might infer, incorrectly, that San Diego is west of Reno. Stevens and Coupe have shown that people commonly make such errors in spatial judgment due to oversimplification of their stored relations.

6. Mental Maps. People also appear to be able to represent and use survey knowledge in imaginal maps. Such a representation may come from a direct encoding of a physical map in some form, such as an image, that preserves the spatial relations among objects on the map, or it may be constructed out of numerous facts derived from direct visual experience in the environment, behavioral memories, and symbolic abstractions. In either case, this type of memory is essentially visual, and it is most easily acquired by individuals who have vivid visual imagery and good visual memory ability (Thorndyke & Stasz, 1980). Further, such imaginal maps can be examined, scanned, and manipulated in the same manner that one would use a physical map (Thorndyke, 1979).

Depending upon the extent of people's knowledge of a region, their mental maps may vary in the amount of detail they contain. Individuals with extensive navigational experience or who have studied a map may possess nearly veridical mental maps. I have referred to these in Table 1 as detailed maps. On the other hand, people frequently possess poorly developed maps containing normalized or oversimplified features. I refer to such maps as schematized maps, because they often contain a simple, prototypical configuration of elements. For example, Los Angeles contains a system of streets and freeways that approximate, although differ in significant ways from, a rectilinear grid. People who have lived in Los Angeles for a short time frequently assume that most streets are parallel or perpendicular to each other. When these individuals draw maps of the city they make relational errors based on these assumptions of regularity. Further, they are surprised to learn that two streets that they had assumed to be parallel actually intersect. Chase (in this volume) illustrates this phenomenon of systematic normalization of spatial relations in students' reconstructions of the map of the Carnegie-Mellon campus.

KNOWLEDGE TYPES AND SPATIAL JUDGMENTS

These distinctions among knowledge types become more salient when we consider the estimates and judgments people make using their spatial knowledge. My colleague Barbara Hayes-Roth and I have developed the idea that the different categories of knowledge described above may be optimal for different tasks requiring spatial judgments (Thorndyke & Hayes-Roth, Note 1). Further, the method by which people acquire their knowledge of the environment influences the type of

knowledge that they have and the way in which it is represented. This suggests that people's performance on reasoning tasks depends on the type of experiences that have contributed to their spatial knowledge.

For example, navigational experience in a region leads directly to procedural knowledge. Such knowledge encodes the products of direct experience, including perceptual icons and the actions associated with those icons for traversing particular routes. The knowledge a person acquires directly about the space between two points when navigating comprises a sequence of turns at perceptible angles and the distance, experienced visually and kinesthetically, along each of the legs of the route. It is thus possible to obtain fairly precise local knowledge of the space and the route distance that connects the two points. In addition, as Tolman (1948) has demonstrated with rats and Kozlowski and Bryant (1977) with humans, navigational experience leads relatively rapidly to accurate orientation knowledge (the ability to point to unseen locations in the environment). This latter knowledge is particularly useful for dead reckoning in an unfamiliar environment (i.e., navigating in the general direction of an unseen destination) and for locating oneself in the environment with respect to other objects or locations.

On the other hand, when people study a map of the same region they have immediate access to the configural properties of the region. Because knowledge of the region is spatially rather than sequentially available, the global relationships among objects in the region are readily apparent. These relationships include the relative locations of and euclidean (straight-line) distances between objects in the region. Thus, for example, if one views a map of Los Angeles, it is

easy to discern whether UCLA or USC is closer to Rand and what their relative locations are. However, if one is restricted to driving among those points, the relative euclidean distances and spatial locations may be quite difficult to ascertain.

The city of Boston provides an excellent environment with which to illustrate the distinction between reasoning from procedural knowledge and reasoning from survey knowledge. Because the major geographic boundaries (the harbor and the Charles River) and many of the roads contain irregular curves, it is difficult to induce accurate survey knowledge of the city without looking at a map. In fact, it is not unusual for residents of the city to know how to navigate between points in the city along the best routes (which are not the shortest routes) but not be able to draw a map of the city that properly locates the same points.

Of course, Boston is an extreme example of the difficulty of inducing survey knowledge from navigational experience because of the severe irregularities of the common routes. In many regions, people can learn the spatial relationships well enough to draw a reasonably accurate map after a moderate amount of navigational experience. This illustrates another point about the acquisition of spatial knowledge: the type of knowledge a person has about an environment usually changes over time and with increasing experience in the environment.

In an experiment designed to illustrate these points, Hayes-Roth and I tested various spatial reasoning skills of subjects who had had different learning experiences. We selected as our test environment the two buildings of The Rand Corporation, a maze of offices and hallways that most employees require a few weeks to master. Half of our

subjects learned the Rand environment by memorizing a map of the floor plan of the two buildings. These subjects thus directly encoded a survey representation of the space. The map-learning subjects had never visited Rand prior to the experiment. The other subjects were Rand employees who had obtained their knowledge of the buildings by navigating through the hallways. We manipulated the amount of experience these subjects had had by selecting employees who had worked at Rand for either a month, six months, or 12 to 24 months.

We tested the spatial knowledge of our subjects on orientation, distance estimation, and object location tasks. For the orientation task, we took subjects to various locations in the building and asked them to point in the direction of other, unseen locations. Subjects with only one month of navigation experience performed more accurately on this task than subjects who had memorized the map. Furthermore, the longer individuals had worked at Rand, the more accurate their orientation judgments were. On the object location task, subjects were given a piece of paper with two locations in the building specified and were required to mark the correct location of a particular third location. This test evaluated the accuracy of subjects' survey knowledge of the building. Subjects who had learned the map performed better than all navigation subjects, although the navigation subjects again improved with increasing experience. This result emphasizes the important distinction between the knowledge required to orient oneself in the environment and the knowledge required to reconstruct a survey representation.

Subjects performed two types of distance estimation between various sets of points: route distance (distance along the hallways between the two points) and euclidean distance (straight-line distance). Subjects who had learned the map could readily compute from memory both types of distance; accordingly, they were equally accurate on both types of estimate. However, subjects with one month of navigation experience were far superior in their route estimates and inferior in their euclidean distance estimates. While direct navigational experience led to superior knowledge of the distances along traveled hallways, the survey knowledge subjects obtained from learning the map was optimal for computing euclidean distances. Interestingly, performance on both estimation tasks improved with increasing experience, so that subjects with 12 to 24 months' experience were equally accurate on both types of estimates and superior to the map-learning subjects.

These results illustrate three important points about spatial cognition. First, different spatial reasoning tasks require the use of different types of knowledge. While survey knowledge, for example, may be appropriate for judgments of relative location and distances among objects, it is not optimal for judgments of spatial orientation. Second, different experiences induce, at least initially, different types of knowledge. This was illustrated in the performance differences of subjects who had studied a map and subjects who had traveled throughout the building. Finally, spatial knowledge evolves and changes with extensive navigational experience. While such experience initially produces primarily procedural knowledge, increasing the amount of experience induces survey knowledge perhaps as accurate as that obtained from learning a map.

INDIVIDUAL DIFFERENCES IN SPATIAL COGNITION

While the previous section outlined some general principles of spatial cognition and reasoning, an equally important source of variation in spatial reasoning performance is the spatial processing skill and style of the individual. These individual differences include both the strategies people use and the basic cognitive processing abilities required to perform spatial cognition tasks. One of the first psychologists to study individual differences in the processes of spatial cognition was Trowbridge (1913), who investigated different strategies and individual abilities for orientation. In this section, I will illustrate some of the dimensions of individual variation using the task of map learning, since maps are perhaps our most common source of survey knowledge.

An implicit assumption in the previous discussion of map representations in memory, and one I have defended elsewhere (Thorndyke, 1979), is that learning a map entails the creation of a visual representation in memory. Creating a visual representation of a display as complex as a typical map depends both on learnable strategies for focusing attention on the display and organizing the visual field, and on more stable, fundamental skills, such as encoding and manipulating visual information in mental images. Cathleen Stasz and I, in a series of experimental studies (Thorndyke & Stasz, in press), have been investigating the predictability of people's success at learning a map from their study strategies and spatial abilities.

Initially, we gave subjects a map to learn containing both spatial information (e.g., road patterns, rivers, building locations) and verbal information (named objects and locations). On each of six

study/recall trials, subjects first studied the map for two minutes, attempting to learn as much of the map as they could. After the two minutes, subjects drew from memory as much of the map as they could remember. While subjects studied the map, they thought out loud about what they were looking at on the map, what techniques they were using to learn the information, what information they thought they had yet to learn, how they were deciding to change study strategies, and so on. By analyzing these verbal protocols for the set of "procedures", or study techniques, that subjects were using, we were able to relate speed of learning over trials to the set of study procedures subjects employed.

Three general types of procedures emerged from the protocols: attention, encoding, and evaluation. Attentional procedures included those by which subjects selected subsets of the map information on which to focus and those by which they decided the sequence of map elements to study. Encoding procedures included techniques for holding current information in working memory and techniques for elaborating the information and storing it in long-term memory for later retrieval. Predictably, the procedures that emerged from the protocols for encoding spatial information were different from those used to encode verbal information. The evaluation procedure comprised subjects' statements of whether or not they felt they had successfully learned the information on which they were currently focusing.

A comparison of the protocols of fast and slow learners revealed at least one difference in the use of procedures in each of the three categories. Good learners controlled their focus of attention on the map by isolating subsets of information and systematically learning

the information in each subset before moving to a new one. Poor learners used more haphazard and unsystematic approaches to selecting information to learn. Good learners were more accurate in their self-evaluations of what they knew or did not know than poor learners. Further, when they decided that they did not yet know certain information, they were more likely to immediately attempt to learn that information than poor learners. Finally, and most importantly, good and poor learners differed in the encoding procedures they used to actually learn the information on the map. While both good and poor learners were successful at learning the verbal information on the maps, good learners were far superior at learning the spatial information. They used a variety of techniques for learning spatial shapes and relationships, including visual imagery, encoding explicit spatial relationships between pairs of map objects (e.g., "the church is west of the fire station"), and naming a complex spatial configuration as a cue for reproduction of the shapes later (e.g., "this set of roads looks like a stick man running to the west"). In contrast, poor learners were unable to learn much of the spatial information and used far fewer spatial learning procedures.

While the major difference between good and poor learners was in their success at learning spatial information, the relationship between performance and the use of study procedures was correlational. Thus, it was not clear that the use of effective learning procedures was the underlying determinant of the superior performance of good learners. Therefore, in another experiment, Stasz and I manipulated the procedures subjects used in order to assess directly the influence of particular procedures on learning success. We divided a sample of

subjects into three groups and gave each group a map to learn using their own techniques, as in the first experiment. We then trained the first group to use a set of six procedures that had been highly correlated with learning success in the previous experiment. Three of these procedures were techniques for learning spatial information and included instruction in the use of visual imagery. The second group received training on six procedures that were uncorrelated with success in the first experiment. The third group received no training. Subjects then studied a second map on which they were instructed to use the procedures they had been taught. The group instructed in the use of the effective procedures improved their performance significantly more than the other two groups, indicating that the use of effective procedures contributed directly to subjects' learning success.

We also assessed the basic visual ability of all subjects by administering a psychometric test of visual memory. Essentially, this test measured subjects' ability to create, maintain, and retrieve a visual image in memory. We reasoned that the ability to encode visual information in memory might influence the benefit subjects derived from training in the use of spatial learning procedures. An analysis of the post-training performance of subjects in the effective procedures group indicated that visual memory ability did influence learning performance on the second map. In general, the higher a subject's visual memory ability, the greater the improvement in performance over the first map. For subjects of high and medium ability, the extent of the improvement was significantly greater than for the subjects in the other two training groups. However, low-ability

subjects improved no more than subjects in the other groups, indicating that they benefited little from the effective-procedures training. Thus, both people's basic skills at using spatial information and the discretionary study techniques they employ play important roles in their spatial cognition.

CONCLUDING COMMENTS

In surveying some of the current research in spatial reasoning being conducted by cognitive psychologists, I have been motivated by two goals. The first goal has been to present and attempt to defend a few of the hypotheses about human spatial cognition that guide my research. In summary, these hypotheses are that (1) people have and use a variety of types of spatial knowledge, (2) the type of knowledge people have about a region depends on the nature of their experiences with the region, (3) for many spatial reasoning tasks, performance is constrained by the type of knowledge available to the individual, and (4) people's low-level spatial processing skills may limit the available forms of knowledge representation and task performance. The second goal has been to attempt to narrow the gap between the concerns of cognitive and environmental psychologists studying spatial reasoning. Historically, this gap seems to have resulted primarily from differences in problem domain and in methodology. While environmental psychologists have, by and large, investigated real-world problems using observational or correlational methodologies, cognitive psychologists have traditionally conducted experimental studies of performance on simplified laboratory tasks. Although some of the tasks discussed in the previous sections used stimulus materials that were

specially constructed for the experiments, the tasks themselves represented activities that people normally perform when learning and reasoning in their environment. In addition, an attempt was made to illustrate some alternative research paradigms that appear promising in the study of cognitive aspects of spatial behavior, including correlational methods such as protocol analysis used in conjunction with experimental studies. Inasmuch as the study of human spatial behavior is a growing concern in both disciplines, the exchange of knowledge across disciplines is clearly in the interest of researchers in both fields.

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